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佛山市禅西大道塱沙大桥主桥中跨合拢段轴向受力分析

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摘　要:悬臂浇筑预应力混凝土连续梁桥由于其跨越能力强、施工便捷、造价经济等特点而被广泛的应用。合拢段施工是悬臂浇筑预应力混凝土连续梁桥施工和体系转换的重要环节,而中跨合拢段的施工更是合拢段施工的重点和难点。通过塱沙大桥主桥中跨合拢段的轴向受力的计算来对悬臂浇筑混凝土梁的中跨合拢段轴向受力特点进行详细的介绍,有关经验可供相关专业人员参考。

关键词:悬臂浇筑;预应力混凝土连续梁;合拢段;轴向受力
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1　概况

佛山市禅西大道是 325 国道改线段的重要组成部分,路线起于罗村街边佛山机场南的省道桂丹公路(规划横三)处,终点位于季华路,路线全长约 6.1 km。全线共设置互通立交两座,分离式立交一座和大桥(即塱沙大桥)一座。塱沙大桥在路线桩号 K1+500 处上跨汾江河。

跨越汾江河主桥采用的结构是 46.75 m+75 m+45 m 变截面预应力混凝土连续梁,主跨支点处梁高 4.2 m,跨中梁高 2.1 m,梁底按二次抛物线 $y=4f(L-X)X/L^2$ 变化,箱梁由顶板形成单向 2% 的横坡,梁高均为结构中心高度。箱梁为单箱双室截面,箱底宽 12.25 m,箱顶宽 19.25 m,箱梁翼缘宽度每侧均为 3.5 m,箱梁顶板厚度一般为 25 cm,中墩支点处取 55 cm;箱梁腹板厚度取用 55 cm,中墩支点截面除 0# 号块外为 80 cm,0# 块截面为 90 cm,边墩支点截面为 80 cm;箱梁底板厚度变化范围从 25~60 cm,中墩支点处取 90 cm;翼缘板端厚度为 20 cm,中间折点处厚度为 35 cm,根部厚度为 60 cm。

主桥平立面、跨中断面、支点断面见图 1~图 3。

2　中跨合拢设计

2.1 中跨合拢工艺

由于是中跨合拢段,合拢段两端的梁体都是 T 构悬臂端。悬臂端的自由度比较大,在温度、日照等因素的作用下,会发生轴向收缩、竖向挠曲、水平偏移。在混凝土强度未达到设计要求、合拢段预应力钢束未张拉之前,以上种种变形会导致合拢段混凝土的开裂。因此,必须采用有效的措施来保护合拢段混凝土,避免其开裂破坏。

为了保护合拢段混凝土,设计在合拢段处采用了外刚性支撑的合拢锁定装置。此种装置是在箱梁的顶、底板的顶面预埋钢板,设置反力座,并将外刚性支撑焊接在其上,依此共同锁定合拢口(见图 4)。

安装锁定装置后,由于温度升高梁体伸长而产生的压应力将主要由锁定装置承担,避免了合拢段混凝土承受较大的压应力。同时,在合拢段设置纵向临时预应力钢束,并进行张拉,以预压力来抵消两端因温度降低而缩短所产生的拉力(见图 5)。

这样通过设置合拢锁定装置和临时预应力钢束,避免了合拢段混凝土在强度达到设计要求前承受较大的拉、压力,使其得到了有效的保护。

2.2 中跨合拢段纵向受力计算

在中跨未合拢前,为保证结构稳定,两个中墩支点处的支座约束都应为固结约束,墩身无位移。轴向受力简图如图 6 所示。

设梁体升温 $\triangle t$ 时产生的自由伸长量为 $\triangle L_t$,故:

$$\triangle L_t=a_g\triangle tL_g+2a_h\triangle tL_h$$

因梁体与合拢段连接钢材协同变形,故可取 $a_g=a_h$,

所以 $\triangle L_t=a_g\triangle t(L_g+2L_h)=a_h\triangle tL$

温度升高时梁体膨胀,而梁体两端固结,故两端会产生约束轴向力 N,N 使梁体产生得变形为:

$$\triangle L_n=(NL_g)/(E_gA_g)+2\sum_{i=1}^{n}(NL_h^i)/(E_hA_h)$$

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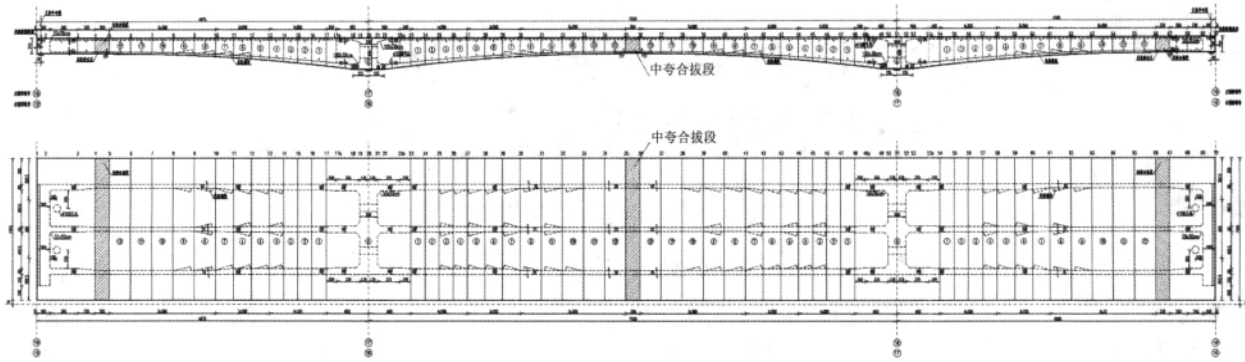

图 1 主桥平立面(单位:cm)

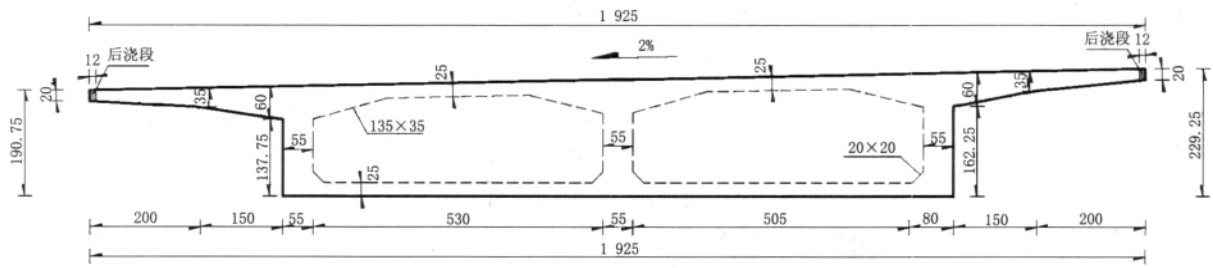

图 2 跨中断面(单位:cm)

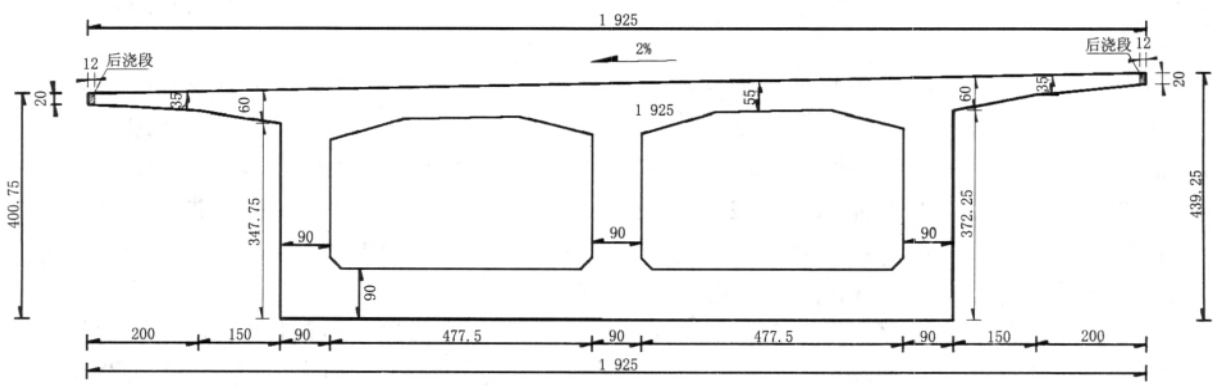

图 3 支点断面(单位:cm)

根据变形协调原理,$\triangle L_t = \triangle L_n$,所以:

$$N=\frac{a_h \triangle t L}{\left[\frac{L_h}{E_g A_g}+2\sum_{i=1}^{n}\frac{L_h^i}{E_h A_h}\right]}$$

式中:N——梁体温度变化时所受得轴向力;

a_h, a_g——分别为混凝土和钢的线膨胀系数;

L,L_g,L_h——分别为合拢段总长及悬臂段总长和合拢口的钢支撑长度;

E_g,E_h——分别为钢和混凝土的弹性模量;

A_h^i —— 箱梁第 i 段的平均面积;

L_h^i ——箱梁第 i 段的分段长度。

L_h 共分 15 段,分段示意见图 7。

各分段参数见表 1。

a_h=0.000 01/m/℃,L=75 m=75 000 mm,L_g=2 m=2 000 mm。

连接钢材面积:连接钢材采用 I40 工字钢,单根面积为 10 211.2 mm²,共 36 根,

所以 A_g=36×102 11.2 cm²=3 676.032×10⁴ mm²

E_g=2.06×10⁵ MPa E_h=3.45×10⁴ MPa

$$\sum_{i=1}^{n}\frac{L_h^i}{A_h^i}=\left(\frac{1.25\times10^3}{53.975\times10^6}+\frac{1.0\times10^3}{22.465\times10^6}+\frac{3.75\times10^3}{21.175\times10^6}+\frac{2\times10^3}{19.82\times10^6}+\frac{2\times10^3}{18.995\times10^6}+\frac{2.0\times10^3}{18.23\times10^6}+\frac{2.0\times10^3}{17.52\times10^6}+\frac{2.5\times10^3}{16.795\times10^6}+\frac{2.5\times10^3}{16.07\times10^6}+\frac{2.5\times10^3}{14.71\times10^6}+\frac{3.0\times10^3}{13.445\times10^6}+\frac{3.0\times10^3}{13.005\times10^6}+\frac{3.0\times10^3}{12.67\times10^6}+\frac{3.0\times10^3}{12.45\times10^6}+\frac{3.0\times10^3}{12.34\times10^6}\right)$$

=2.324 43×10⁻³/mm

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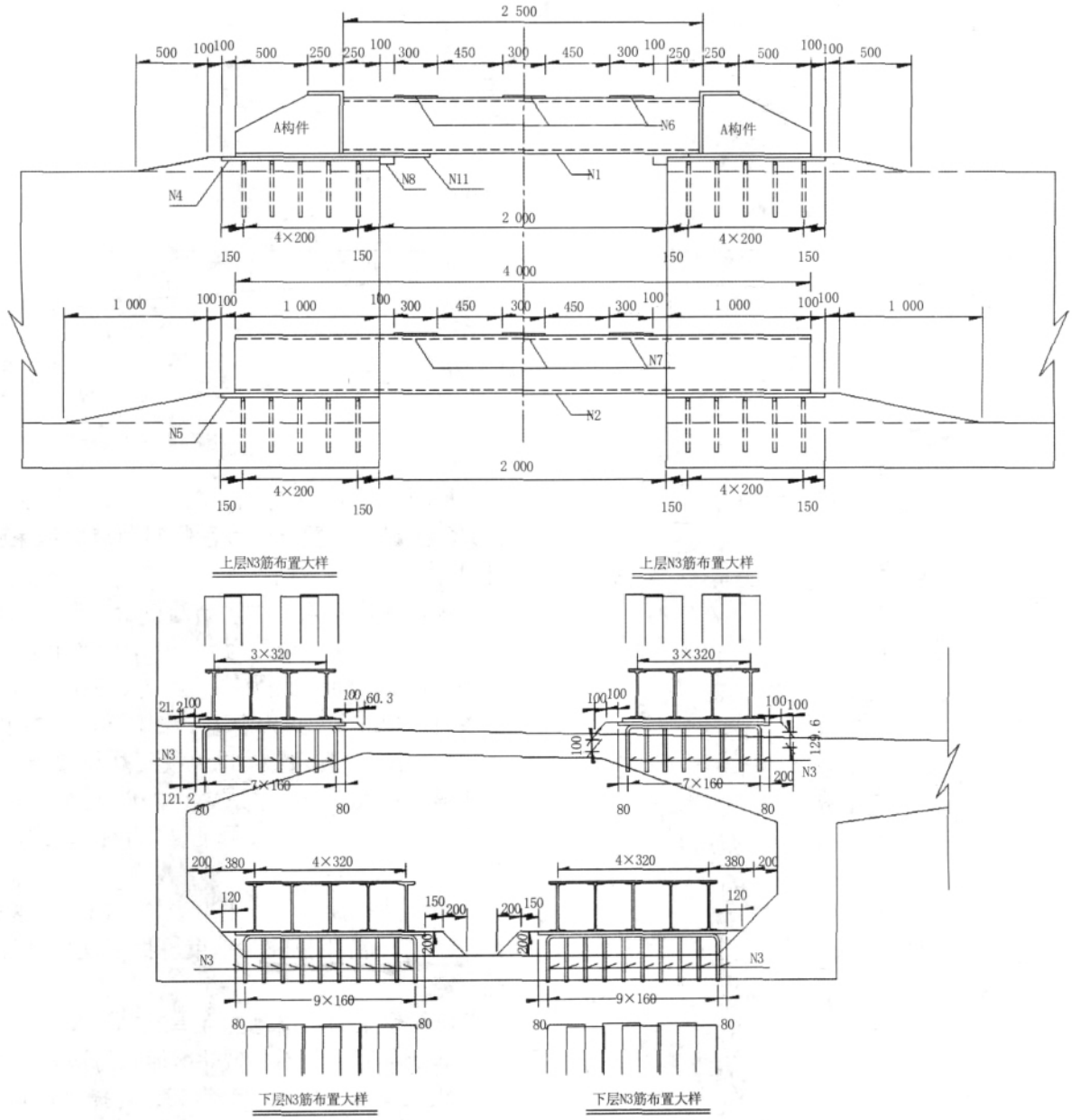

图 4　锁定装置构造图(单位:cm)

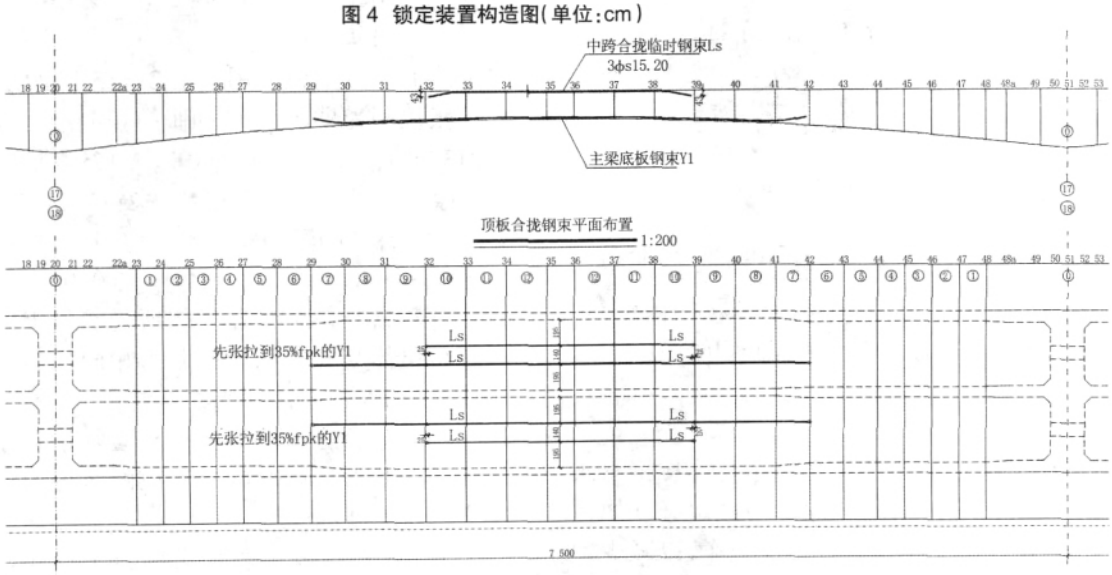

图 5　合拢钢束布置图(单位:cm)

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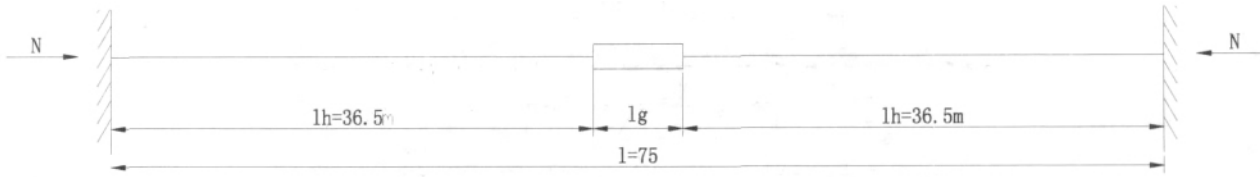

图 6 纵向受力简图

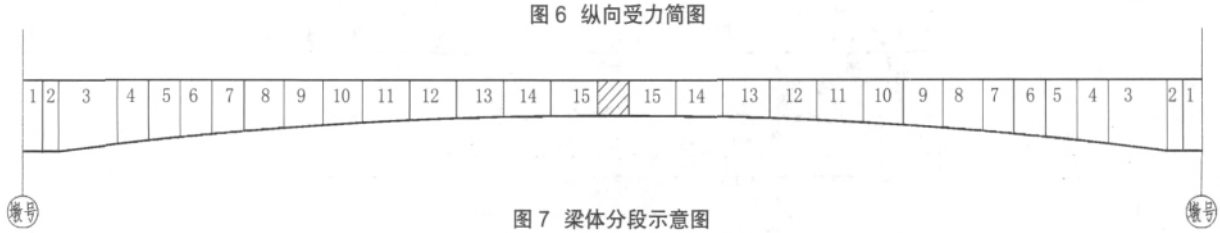

图 7 梁体分段示意图

表 1 梁体分段参数表

分段编号	$S_{左}$ /m²	$S_{右}$ /m²	$S_{均}$ /m²	L_h^i /m
1	53.975	53.975	53.975	1.25
2	27.92	22.01	24.965	1
3	22.01	20.25	21.13	3.75
4	20.25	19.39	19.82	2
5	19.39	18.6	18.995	2
6	18.6	17.86	18.23	2
7	17.86	17.18	17.52	2
8	17.18	16.41	16.795	2.5
9	16.41	15.73	16.07	2.5
10	15.73	13.69	14.71	2.5
11	13.69	13.2	13.445	3
12	13.2	12.81	13.005	3
13	12.81	12.53	12.67	3
14	12.53	12.37	12.45	3
15	12.37	12.31	12.34	3

$L_g/A_g=2\times10^3/3\ 676.032\times10^4=0.544\times10^{-4}/mm$

$$\left[\frac{L_g}{E_gA_g}+2\sum_{i=1}^{n}\frac{L_h^i}{E_hA_h}\right]=\frac{0.544\times10^{-4}}{2.06\times10^6}+2\times\frac{2.32\ 443\times10^{-3}}{3.45\times10^4}=135.014\times10^{-9}\ mm/N$$

所以 $N=\frac{10^{-5}\Delta t75\times10^3}{135.014\times10^{-9}}=5\ 555\Delta t(kN)=555.5\Delta t(t)$

故中跨合拢锁定后，梁体温度每变化 1℃，将会产生 555.5 t的内力，若昼夜温度相差 10℃，取 $\Delta t=10$℃ 计算得：

N=5 555 t

如此大的内力无论是对梁体还是连接钢材来说都是非常不利的，因此合拢口的锁定必须快捷迅速完成，在锁定前做好一切准备工作，以减少锁定时间。锁定后立即解除一侧中墩支点的固结约束，使梁体能够自由伸缩。

2.3 合拢锁定装置及合拢段临时预应力钢束受力计算

锁定完成解除一侧固结约束后，温度变化再引起梁体伸缩，当收缩力大于中墩的摩阻力时，梁体就能自由滑动，收缩力就不会加大，所以梁体及合拢段所受的最大温度内力等于梁体与支座之间的摩阻力。中墩施工阶段最大的恒载反力为 42 000 kN，对于盆式橡胶支座摩擦系数取 0.06，故：

合拢段所受最大降温拉力 F＝42 000×0.06＝2 520 kN

为保证合拢段混凝土不受拉，确保混凝土的浇筑质量，需张拉临时钢束以抵消这部分拉力，故：

临时钢束的张拉力 N_y>F＝2 520 kN

底板临时钢束不再另外增加新的钢束，采用 2 根底板束 Y2（12φ15.2）钢束，合拢时将其张拉 35%的张拉控制力即为 2×12×139×1 860×0.35×0.001＝2 171.8 kN

顶板临时钢束采用 4 根 3φ15.2 钢束，合拢时将其张拉制力即为 70%的张拉控制应力即为 4×3×139×1 860×0.7×0.001＝2 171.8 kN

故总的临时钢束力 N_y＝2 171.8+2 171.8＝4 343.6 kN，考虑 30%的预应力损失，故：

N_y＝3 040.5 kN，安全系数 γ=3 040.5/2 520=1.21。

当升温时，合拢段梁体所受的最大的伸张力也应与梁体与支座间的摩阻力相同，故：最大张力 P＝2 520 kN。

为了保护合拢段混凝土，必须设置刚性支撑装置抵抗此力，同时临时钢束的张拉力也要由刚性支撑装置抵抗，故：

刚性支撑装置所受最大压力 N＝P+N_y＝2 520+4 343.6＝6 863.6 kN

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故刚性支撑最大截面 =6 863.6×1 000/(3 676.032×10 000)<140 MPa

3 结论

通过以上对中跨合拢段的分析计算，可以得出以下结论：

⑴ 中跨合拢段的施工必须配合使用合拢段锁定装置及合拢段临时预应力钢束。只有采用了上述措施，才能使合拢段混凝土在浇筑初期得到有效的保护。

⑵ 必须减少合拢段的锁定时间，在锁定之前应做好合拢装置焊接及临时钢束张拉的准备工作。在合拢口锁定后，为避免梁体出现较大的内力，应立即释放一侧的固结约束，使得梁的另一端在锁定装置的连接下能够自由的伸缩。

⑶ 合拢段的施工应选在风力很小且温度变化幅度较小的深夜进行。第一，夜间温度变化幅度较小，对合拢段受力更加有利；第二，由于夜间温度相对较低，合拢段混凝土浇筑完成后，温度将会逐渐升高，合拢段混凝土将逐渐承受压力，这对于合拢段的混凝土的受力较为有利；第三，由于夜间没有日照，且风力较小，避免了合拢段混凝土在浇筑初期发生竖向挠曲及横向水平变形。

⑷ 若合拢段混凝土在夜间进行浇筑，则合拢段的临时钢束应在合拢段混凝土浇筑的第二天温度回落前进行张拉。此时温度开始降低，梁体开始收缩，此时进行预应力的张拉，预应力的利用效率最高。

⑸ 合拢段的混凝土宜比梁体提高一个等级，并要求采用早强微膨混凝土。

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明显，横向分布系数为最小，而中梁的横向分布系数依旧为最大。各主梁负弯矩值会达到一个最大值。在施工合龙时，一定要注意主梁的弯矩变化情况，避免因结构内力剧烈变化导致局部应力过大问题。

4 结论

通过对施工阶段仿真分析计算，可以得出以下结论：

⑴ 茜草长江大桥主桥施工阶段结构安全可靠，在各种不利情况下，箱梁、塔、斜拉索和桥墩均能满足规范要求，并有较高的应力储备。

⑵ 在施工过程中，要密切注意宽箱梁主梁内力横向分布变化情况，并由此导致的宽箱梁横向应力不均匀现象，防止因局部应力过大造成混凝土开裂。

通过对茜草长江大桥主桥施工过程的模拟仿真分析，了解各施工状态下结构的变形和受力特点，分析了宽箱梁内力横向分布状况，为桥梁的施工控制提供了依据，可以保证施工过程的顺利进行，并为同类桥梁的设计和施工监控提供有益的参考。

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武汉将建公铁两用长江隧道　水底借道成江城新景

武汉市明年将投资约 80 亿元，新建一条中国最宽的长江隧道。这条长江隧道是武汉三阳路过江通道，也是国内第一条公铁合一的长江隧道。三阳路隧道为公铁同管合建，上层为机动车道，双向 6 车道，下层是轨道交通 7 号线（东西湖金银湖 - 武昌区南湖）及疏散通道等。隧道全长 5 730 m，总投资预计 79.50 亿元，工期 54 个月。国内目前只有上海建成了公铁两用长江隧道，三阳路隧道直径达 15.2 m，超过上海隧道，是国内最宽的长江隧道。

江河分割、湖泊密布，“滨水之城”武汉发展交通绕不开水，借道水底、穿江入湖已成江城新景。目前，武汉已建成“万里长江第一隧”——青岛路长江隧道、水果湖湖底隧道，在建地铁 2 号线穿越长江隧道，明年还计划新建东湖湖底隧道。

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resistance of roadbed when the road crosses the reserved coal column section of the goaf in coal field, the technology of grouting treatment and the inspecting test scheme to inspect and test the deforming resistant effect of roadbed. The technical measures can be referred for the similar projects.
Keywords: goaf of coal field, deforming resistance of roadbed, grouting treatment, slurry mix proportion, construction technical design parameter, quality inspection test

Discussion on Technology of Grouting Material and Grout Mix Proportion in Grouting Treatment Test Project of Goaf in Coal Field ..... Liu Zhen, Chen Shuqiang, Chen Xin (14)
Abstract: With the high-speed development of the national economy in China, the influence of the coal field goaf is greater and greater on the city development. The grouting method is more used to treat the goafs at home and abroad now, which grouting material and the mix proportion reasonably to select is extremely important for the quality, cost and construction period. Combined with Urumchi Outer Ring Road Northeast Section Liudaowan Coal Field Goaf Roadbed Deformation Resistant Grouting Treatment Test Project, and according to the analysis and study of this test results, the reasonable grouting material and grout mix proportion is given to suit this project, and the engineering experimental experience is accumulated for the similar projects so as to further perfect the grouting treatment technology of goaf.
Keywords: grouting material, slurry mix proportion, Urumchi Outer Ring road

Evaluation and Analysis on Asphalt Mixture Performance of Runway Pavement in Liuting Airport .....
..... Feng Lei (18)
Abstract: The article introduces the evaluation and analysis of asphalt mixture performance of the runway pavement in Qingdao Liuting Airport, in order to evaluate the mixture performance of asphalt runway pavement, it is to carry out the field sampling of core drill for pavement. The indoor experiment can test the physical mechanical performance index parameters of asphalt content, asphalt aggregate ratio, mineral aggregate gradation, water stability and loose resistance of mixture. The evaluation analysis result shows that the combination among the layers of asphalt mixture is better, the thickness is basically identical with the design value, and the asphalt content satisfies the design requirement. But there are a few fine aggregates below 0.15 mm, and the performances of anti-water damage and loose resistance are not good. The fog seal should be used for the preventive maintenance.
Keywords: airport, asphalt pavement, evaluation, Qinghai City

BRIDGES & STRUCTURES

Analysis on Stress Performance of Wide-box Beam Low-pylon Cable-stayed Bridge .....
..... Yang Yong, Yu Xiaolin (22)
Abstract: Taking Changjiang River Bridge in Xicao of Sichuan as the engineering background, the article simulates and analyzes the construction process of the wide-box beam low-pylon cable-stayed bridge to give the whole process of loading response for the bridge structure and validate the security of bridge structure. The analysis of the beam grid of wide-box beam shows that the transverse distribution coefficient of wide-box beam of the low-pylon cable-stayed bridge is variable under the different stages. The influence of transverse distribution coefficient on the structure security should be considered during the design and construction control. The article gives some results.
Keywords: low-pylon cable-stayed bridge, simulating analysis, wide-box beam, transverse distribution

Analysis on Axial Stress of Closure Section of Middle Span for Main Bridge of Langsha Bridge in Chanxi Avenue of Foshan City ..... Jiang Feng, Hu Jiang, Cao Jing (25)
Abstract: The cantilever poured prestressed concrete continuous beam bridge is widely used because of its strong spanning capacity, convenient construction and economic construction cost. The construction of

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closure section is the key link in the construction of the cantilever poured prestressed concrete continuous beam bridge and its system conversion, and the construction of the middle-span closure section is more important and difficult in the construction of closure section. The article introduces the axial stress of the middle-span closure section of cantilever poured concrete beam by the calculation of the axial stress of the middle-span closure section of the main bridge for Langsha Bridge in detail. The relative experience can be referred by the relevant professional members.

Keywords: cantilever pour, prestressed concrete continuous beam, closure section, axial stress

Local Analysis of Complex Joints in Design of Jiubao Bridge ..... Yu Gang (30)

Absktract: The article analyzes and discusses the complex joints in the design of overlong bridges, sets forth four aspects of the demand, step, result treatment and problems for attention in the local analysis, and analyzes the cases according to the design of Jiubao Bridge. The calculation process of local analysis embodies the complementary relationship between the local analysis and the integral analysis of the structure.

Keywords: composite arch bridge, 3-dimensional design, design of complex joint, component stability, incremental launching construction, bridge design

Simplified Calculation Formula for Design Seismic Force of Bridge Group Pile Foundation as Capacity Protective Member ..... Yin Pengcheng, Ye Aijun (34)

Abstract: In the seismic design of bridges ductility, the foundation of group pile is designed as the capacity protective member sometimes. Based on this design method, it is required to calculate the seismic inertial force of base slab when the design seismic force of the foundation for the group pile is calculated. The article sets up a two-particle model of base slab - pier beam, analyzes the variable rule of the inertial force of base slab with the variation of pier rigidity, and puts forward the simplified calculation formula of seismic inertial force of base slab and the simplified calculation formula of the design seismic force of the foundation for the group pile. Finally, a finite element model based on a practical bridge project is established. The correctness and practicability of the simplified calculation formula is validated by the elastoplastic time-history analysis.

Keywords: foundation of group pile, design seismic force, capacity protective member, simplified calculation formula

tudy on Seismic Performance of Steel-concrete Combined Structure Cable-stayed Bridge ..... Du Peng, Luo Chunyu, Sun Dongli (38)

Abstract: In order to study the seismic performance of a steel-concrete combined structure cable-stayed bridge under the different pylon beam connection rigidities, the current finite element software MIDAS CIVIL is used to set up the spatial beam grid system model for this cable-stayed bridge, and the response spectrum method is used to calculate its earthquake response under the different pylon beam connection rigidities to achieve the inner force and displacement response of this cable-stayed bridge under the earthquake force. After the comparison and analysis of the calculation results, the article finally determines the connection type of this cable-stayed bridge at the pylon and beam, which can be referred for the design of this bridge and the future engineering application.

Keywords: steel-concrete structure cable-stayed bridge, beam grid system, response spectrum method, pylon and beam connection, earthquake response

Overall Plane Arrangement of Urban Viaduct and Its Application ..... Zhou Shikai (43)

Abstract: The engineering cases set forth the overall plane arrangement scheme of urban viaduct how to scientifically and reasonably carry out the plane design and application in order to overcome the complex

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